Vegetation Condition and Fire Occurrence: A Remote Sending Connection

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VEGETATION CONDITION AND FIRE OCCURRENCE: A REMOTE SENSING CONNECTION

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1998

ABSTRACT

The Normalized Difference Vegetation Index (NDVI) is a measure of plant "greenness" (physiological activity and abundance) developed by the remote sensing community. Weekly updated digital images of NDVI sensed on a 1 km (about 0.6 mi) resolution have been studied for the past 6 years as a means of assessing live vegetation condition for the purpose of fire danger rating. These images, if monitored through the growing season, portray the approximate time of greenup and curing as well as the relative amount and condition of growing plants.

This paper discusses two map types developed from NDVI imagery that were used to monitor plant growth over the general area of the Northern Region of the U.S. Department of Agriculture, Forest Service in 1994. Fire locations and ignition dates reported by multiple Federal and State agencies on ICS 209 forms, and the number of fires and number of acres burned (summarized for agencies by the Forest Service on the daily situation reports), are compared to the vegetation condition maps throughout the fire season.

INTRODUCTION

The amount and physiological condition of live vegetation have a strong bearing on fire behavior. Vegetation that is actively growing, abundant, and high in moisture acts as a strong heat sink to fire--slowing or stopping fire spread. Vegetation that is green and growing, but sparse, may have little effect on fire spread, particularly if continuous dead fuel is present. Vegetation that has grown abundantly in response to adequate soil moisture, then cured in summer drought conditions enhances fire spread and intensity.

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Vegetation reflects and absorbs light in characteristic wavelengths that differ throughout its life cycle. When actively growing, vegetation absorbs light in the red wavelengths while reflecting in the green wavelengths, thus looking green to us. Growing vegetation reflects light in the near infrared (NIR) region of the spectrum. Cured vegetation, by comparison, reflects more light in the red wavelengths, but much less in the NIR.

The remote sensing community has developed a number of vegetation indexes to assess the amount and condition of plants based on reflected light measured by satellite-based sensors. The Normalized Difference Vegetation Index (NDVI), calculated from the amount of reflected light in the red and NIR wavelengths, has shown promise for monitoring vegetation condition for drought stress and for fire danger rating purposes (Anyamba 1994; Lopez and others 1991; Paltridge and Barber 1988; Tucker and Choudhury 1987; Westover and Sadowski 1987). The Earth Resources Observation Systems (EROS) Data Center processes reflectance data collected daily by Advanced Very High Resolution Radiometer (AVHRR) sensors onboard U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) satellites. Every week EROS produces a digital NDVI map, composited over a 2-week period, at 1 km resolution, for the conterminous United States. This data, updated weekly, is available though the Weather Information Management System (WIMS) in 42 blocks. The blocks can be retrieved (Burgan and Hartford 1993; Hartford and Burgan 1993), and interpreted by land managers when viewed on a personal computer using public domain software (Pfirman 1991).

USE OF SATELLITE IMAGERY

Remotely sensed images map vegetation greenness on a weekly basis. The maps offer spatial and temporal displays of live fuel as it greens and flourishes, then reaches maturity and cures, thus moving from a fire retarding to fire enhancing state. Maps allow monitoring of droughty areas, such as known rain shadows, in comparison to adjacent higher rainfall areas. They allow vegetation monitoring over large regions and in areas with limited access, such as wilderness areas.

Monitoring efforts over several years have aided in development of a few map types that show particular promise for displaying and interpreting vegetation condition in a way useful for rating fire danger. Two of these maps have been available for the past few years and are described in Burgan and Hartford (1993). Visual Greenness (VG) maps display NDVI rescaled to a range of 0 to 100 percent representing vegetation conditions ranging from fully cured grasslands (0 percent) to fully green, stocked, and adequately watered crops (100 percent). Relative Greenness (RG) maps compare the NDVI on each pixel to a historical range of

values for that pixel. Values range from 0 to 100 percent of the greenness range measured for each pixel. Greenness values are indicated by color on both maps. Colors range from reds and browns, indicating low values, to deep greens, indicating near maximum greenness.

A new map developed during 1994 compares current vegetation to an average for the same time period (Burgan and others in preparation). Tucker and Choudhury (1987) noted that, based on several years of satellite data, the photosynthetic capacity of vegetation in a particular area and at a particular time, could be determined. They noted that this capacity diminishes due to precipitation shortfalls. Therefore, negative departures from the average condition indicate the occurrence of drought. Based on data from the past 4 years, an "average" greenness map was prepared by EROS for each composite period. Burgan calculated the Cumulative Departure from Average (DA) map to compare NDVI on each pixel of the current image to its average for the same composite period, thus relating the current vegetation state to that generally seen at the same time of year. The DA map illustrates whether each pixel is currently less green (values less than 99 percent colored from yellow to brown to red), about the same (values 99 to 101 percent colored gray) or more green (values greater than 101 percent colored from light to dark green) than average. Because past vegetation conditions have some influence on the current vegetation condition, "memory" is built into the maps. The DA map pixel values are weighted 60 percent to the current 2-week NDVI value, 24 percent for the previous 2-week value, 10 percent for the value two periods ago, 4 percent for the value three periods ago and 2 percent for the value four periods ago.

Currently, the RG and DA maps are prepared from comparisons to maps from 1989 through 1992. In 1995 the average and range will be updated to include 1993 and 1994. While the VG map has merit for displaying vegetation condition, this paper will discuss only the relationship between the RG and DA map values with the progression of the 1994 fire season over the general area of the Northern Region of the Forest Service (see fig. 1).

THE 1994 FIRE SEASON IN THE NORTHERN ROCKIES

The 1994 fire season in the Northern Rockies, like many, was influenced by previous months or years. Rainfall throughout much of the spring and summer of 1993 resulted in a lush growth of herbaceous and woody vegetation across much of the area. Relative Greenness maps displayed 100 percent of potential greenness at some time during 1993 over most of the region. A seasonal maximum map was created for 1993 by compositing the weekly updates to maintain the highest value seen on each pixel during the entire growing season. This maximum RG map

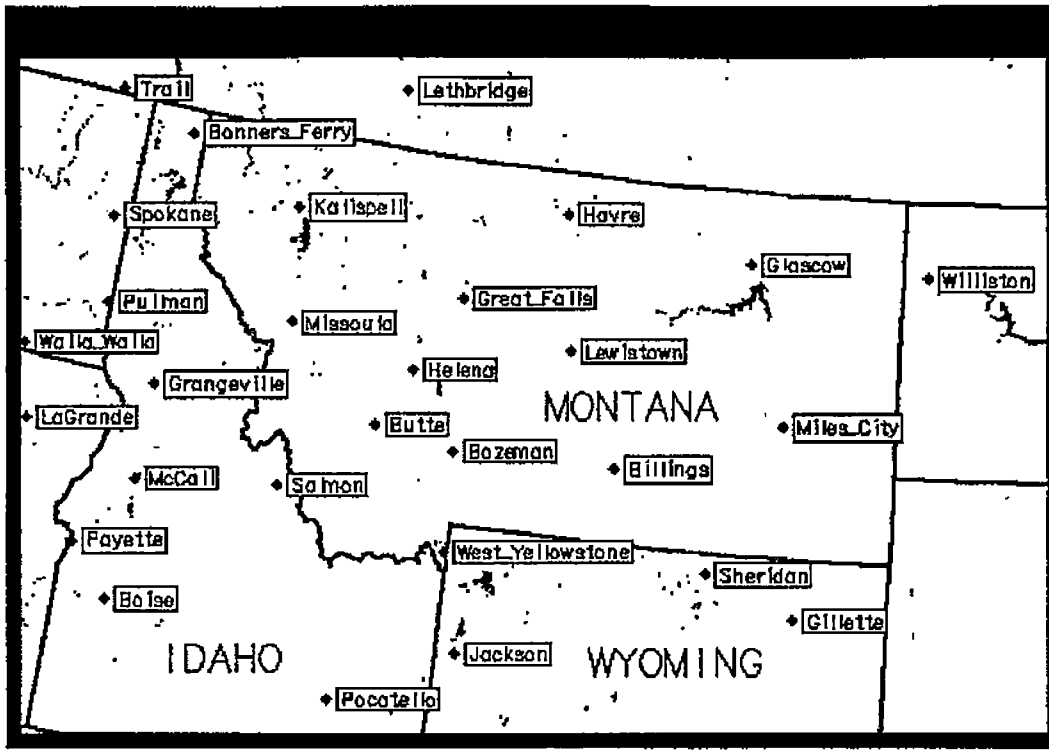

Figure 1 General map analysis area included the Forest Service's Northern Region and immediate surrounding area. Greenness data were summarized over the entire map area and fire data were summarized for reporting agencies within Montana, northern Idaho, and North Dakota.

illustrated that most of the area reached 90 to 100 percent of its historical (1989-1992) range of greenness. The mild, dry winter that followed not only left the dead fuel dry, but also left a considerable amount of the 1993 vegetation still standing or relatively undecayed.

Spring 1994 provided conditions for another flush of vegetation. Temperatures in March, April, and May averaged a few degrees above normal as reported in the "Seasonal Update of the Monthly Temp and Precip Stats for the Last 12 Months" issued from the Missoula Office of the National Weather Service (National Weather Service 1994). Precipitation was very low in March, but, in April ranged from 100 percent of average in Miles City to 313.5 percent of average in Missoula. Rainfall in May was generally 80 to 100 percent of average west of the Continental Divide but highly variable to the east. Rainfall in June ranged from 70-90 percent of average to the west and was highly variable to the east. Most stations throughout the region were near average for the spring, though Helena and Miles City were deficit. Only Billings, Butte, and Missoula received 100 percent or more of average rainfall in July. All stations reported little

precipitation in August and September.

Plots were prepared of the number of new fires (fig. 2), number of new acres (fig 3) and a running total or cumulative graph of the number of fires and number of acres burned (fig. 4) from data obtained from the daily "Situation Report - Areas Summary" prepared by the Northern Rockies Coordination Center (NRCC) for multiple agencies within the general area of the Northern Region. All reporting agencies did not always contribute to the summary daily and the number of new acres reported was not always accurate, but these numbers reflected overall fire activity through the season.

The fire activity graphs show that periods of peak new fire occurrence and peak fire growth did not occur simultaneously. Figure 2 shows short periods of new fire occurrence in late June to early July and in mid July, then high new fire occurrence from the last week of July through the third week of August. From 50 to over a 200 new fires were reported almost daily through the 4-week period with reports peaking at about 5-day intervals as numerous dry thunderstorms passed through the area. The periodicity continued, though at a much lower level of occurrence, through September.

Major peaks in reported new acres (fig. 3) occurred at longer intervals with the largest peak at nearly 14,000 acres in mid September and fire growth continuing into October. Days with high winds were conspicuously lacking over most of the area during the 1994 season. Fires were generally described as fuel driven. That is, most of the fire behavior could be explained by very dry fuels. Had the strong winds that often accompany dry cold front passage occurred, the pattern of fire growth would have looked quite different.

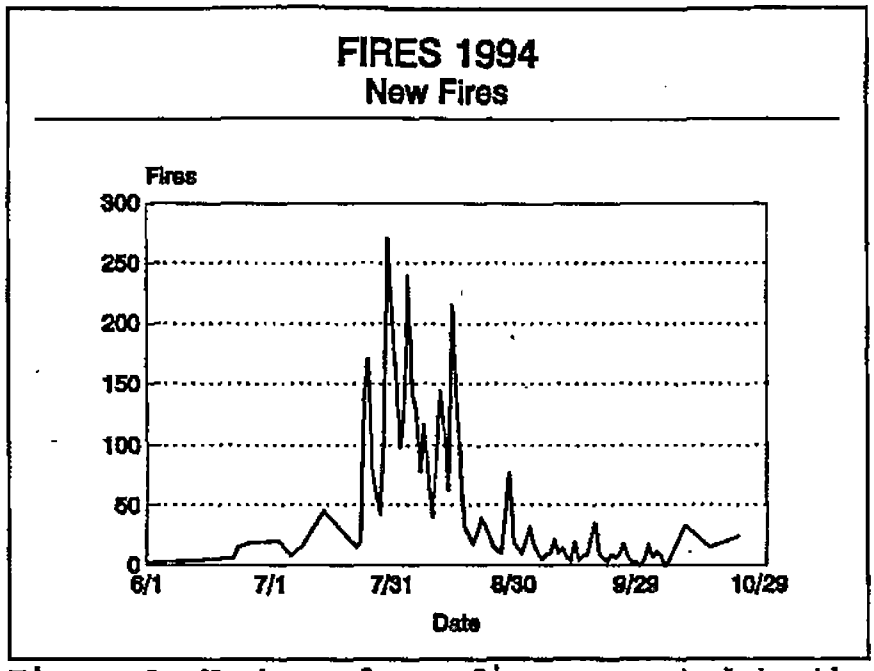

Figure 2--Number of new fires reported to the NRCC on this date.

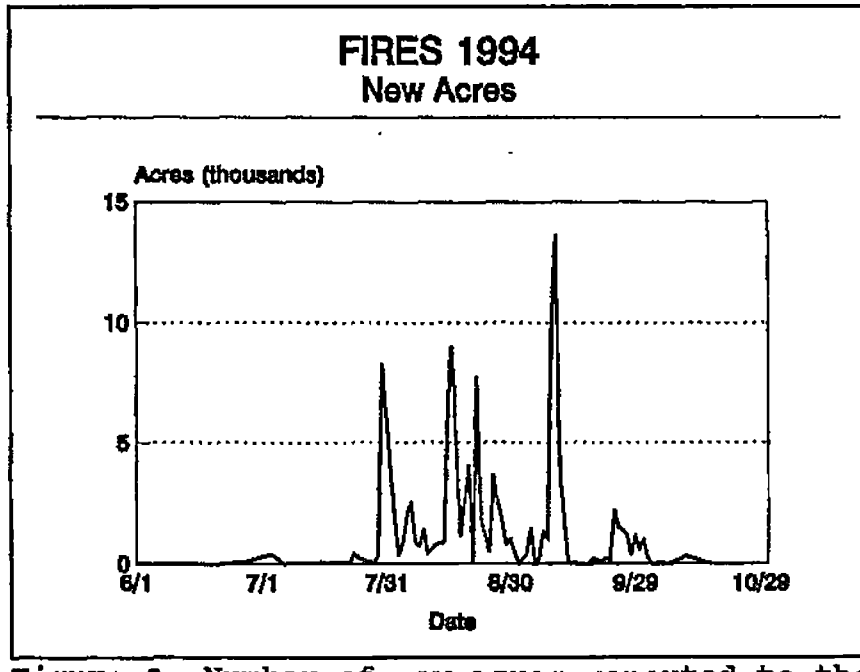

Figure 3--Number of new acres reported to the NRCC on this date.

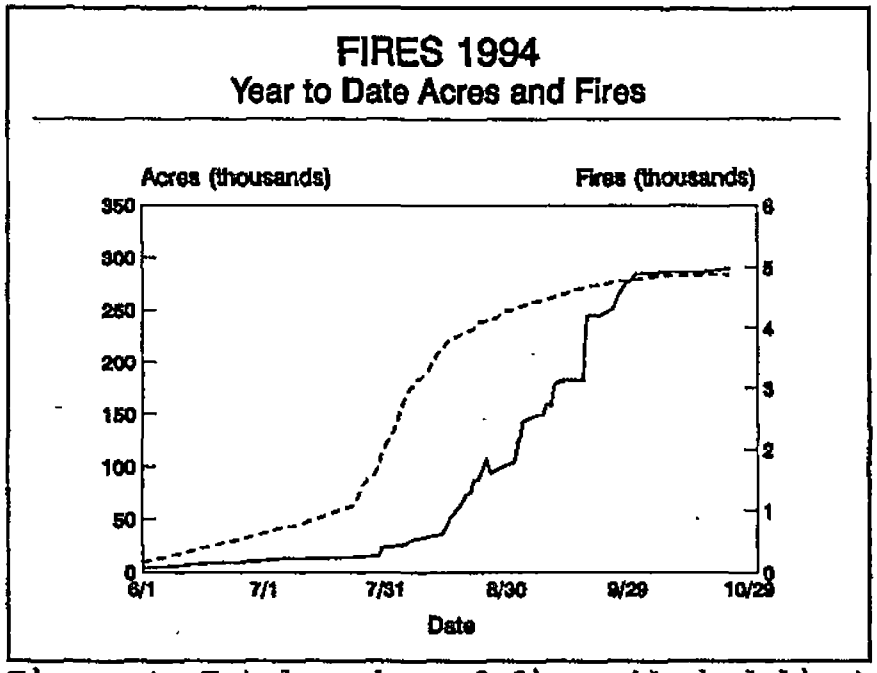

Figure 4--Total number of fires (dashed line) and acres (solid line) reported to this date.

Figure 4 displays a running total of the number of reported fire starts and acres burned for the year to date. The slopes of these lines indicate that while the rate of fire occurrence increased most rapidly from late July to mid August, fire growth increased most significantly from mid August through September as hot and dry weather persisted to dry both live and dead fuel.

SEASONAL PROGRESSION OF VEGETATION CONDITION

Spatial details of the seasonal progression of greenness are typically displayed on a series of color maps. Due to printing limitations, the map sequence cannot be displayed. However, the progression of plant growth and curing shown on the RG maps and the relationship of 1994's vegetation condition through the summer to the average of the past 4 years (DA) will be described.

Maximum RG maps calculated through early July 1994 and again through early August showed much of the region reaching 90 to 100 percent of its potential greenness. In fact, forested portions had higher RG than in 1993. However, several areas, particularly crop and rangeland, displayed noticeably low greenness values on the weekly maps and the deficit was clearly illustrated on the maximum maps. A small area south and west of Kalispell, MT; a

larger area around Spokane, WA; a long sinuous swath through southern Idaho along the Snake River; southern Montana along Beaverhead, Madison, and upper Yellowstone Rivers; and the eastern two thirds of Wyoming fell far short of reaching full greenness. They also cured earlier and more rapidly than surrounding areas. Within these deficit areas, large patches or multiple smaller pockets (a few to several km's across) reached only 20 to 40 percent RG at any time over the season.

The overall change in the relative greenness across the region is displayed in figure 5. The shaded portions on the sequence of graphs show the percent of the map area at each level of relative greenness for six map periods during the 1994 season. The line on each graph displays the cumulative percent of the area equal or less than each relative greenness value. For the period ending 05/26/94, most of the region was well into greenup with about 40 percent of the area in the 60 to 80 percent greenness range. Note the short but separate spike representing areas at 100 percent RG. This represents lower elevation areas primarily in crops or rangeland. By the period ending 07/07/94, most of the region was at its peak greenness with only 27 percent of the area showing less than 70 percent RG. Curing proceeded rapidly over the next 4 weeks so that by 08/11/94, 85 percent of the region was less than 70 percent RG. By the period ending 09/15/94, more than 76 percent of the region was covered by vegetation less than 50 percent RG. The sequence shows that vegetation across the region reached near maximum greenness values over much of the area, then cured rapidly and extensively.

While the Relative Greenness maps display the timing and extent of greenness and curing, the Cumulative Departure from Average maps can be used to compare the current greenness with an average observed for the same time period. In other words, the DA map illustrates whether greenup and curing are progressing at the average rate for the area.

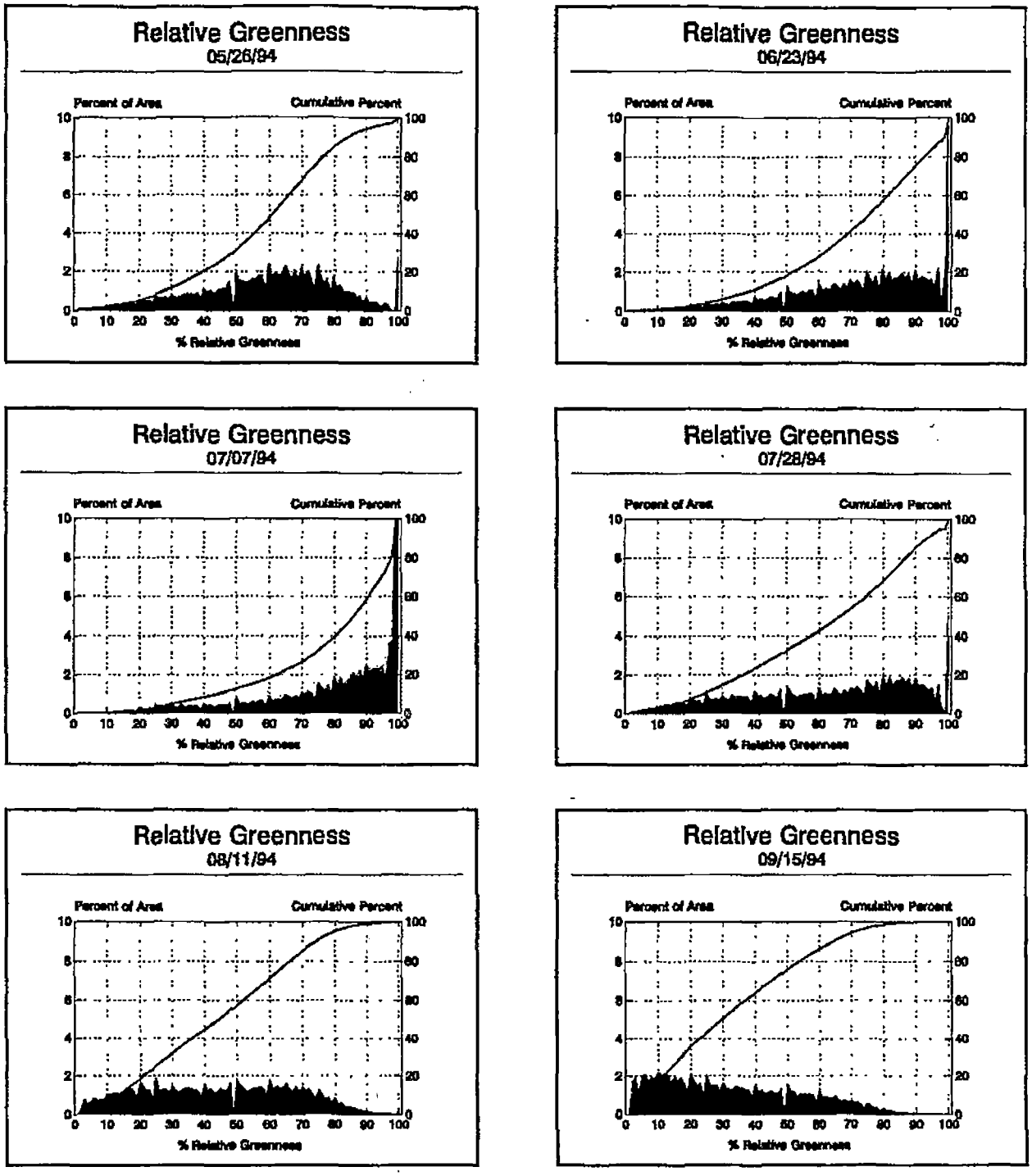

Figure 5--Distribution of Relative Greenness values (shaded area) and cumulative percent of RG values (line) over the Northern Rockies for six 1994 map composite periods, illustrating the change from spring greenup through summer curing.

Cumulative Departure from Average maps were analyzed for the same composite periods as the RG maps described above. Pixel values of 99 to 101 percent DA were considered to represent average greenness. The percentage of the map area displaying less than 99 percent DA was compared between composite periods. The DA map for 05/26/94 displayed only 12 percent of the region at less than 99 percent of average greenness for the time period. By 07/07/94, 17 percent of the area had less than average greenness, indicating advanced greenup in the spring and greater than average greenness over most of the area in early July. The condition changed rapidly in late July. By 08/11/94, 58 percent of the area was less green than average. By 09/15/94, 73 percent of the area was less green than average. Thus, though spring warmth and moisture provided conditions for a greater than average production of green vegetation, curing proceeded faster and to a greater extent than is generally seen over the region.

Two plots of the distribution of area in DA categories are included in figure 6 to show the period of peak greenness and the mid-September period when extensive curing had taken place.

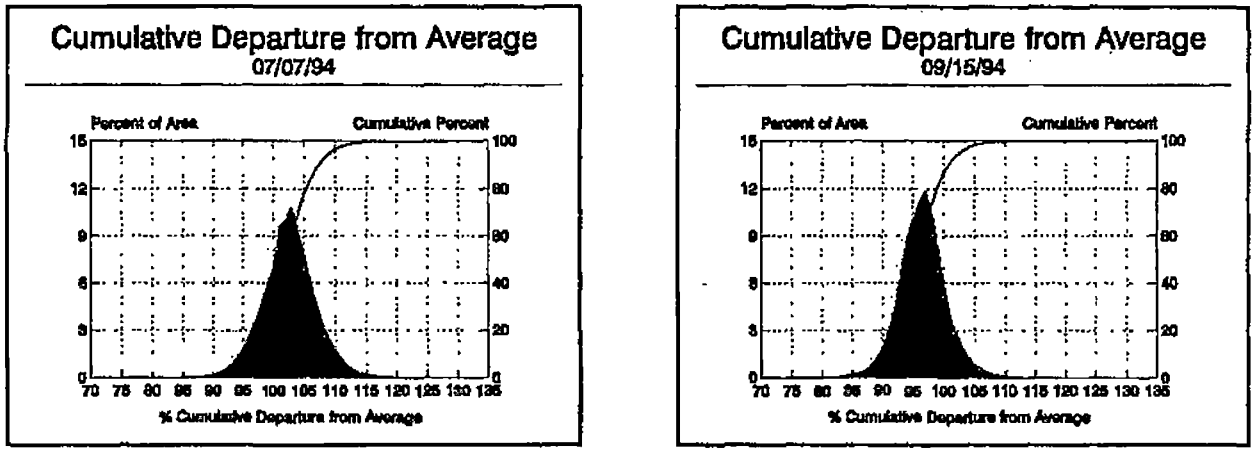

Figure 6--Distribution of Cumulative Departure from Average values (shaded area) and cumulative percent of DA values (line) within the Northern Rockies from DA maps for the composite periods 07/07 and 09/15/94.

General analysis of the maps confirms the vegetation trends observed by fire managers across the region; however, it does not illustrate spatial differences in vegetation condition. Weekly observation of the maps allows specific areas of concern to be monitored. The maps automatically highlight subregional drought patterns as they affect growing vegetation. A low DA value in the spring accompanied by a RG value on the rise may simply indicate a slow greenup and not necessarily a fire prone area.

Most of the region experiences a dry summer season so the average condition of vegetation in July through September is progressive

curing until killing frost, shown on maps by a declining RG value. Thus, once curing begins, a DA value less than average indicates even less green vegetation or more curing than would be expected at that date.

FIRE OCCURRENCE AND VEGETATION CONDITION

Fire occurrence can be related to the vegetation condition maps in two ways. Specific fire locations can be compared to RG and DA values at that location for the map composite period during which the fire occurred. Or, overall fire occurrence, expressed either as the number of fires or the number of acres burned, can be compared to the overall vegetation condition. At the date of this writing, a summary containing locations and final size of all fires within the region is not available. Information relating to the date and the location of fires during the 1994 season was gathered from a number of data tables issued by the NRCC. Data for these tables had been summarized from Incident Status Summary (ICS 209) fire report forms submitted by interagency land managers. These data are preliminary as yet so only a limited analysis can be completed.

Frequent thunderstorms during the 1994 season ensured frequent ignition sources over much of the area. A visual inspection of fire locations plotted on appropriate composite period maps indicated fires occurred primarily in or immediately adjacent to areas showing lower RG or DA values than the area in general. Table 1 displays the vegetation condition values for a few of the fires in the Northern Rockies in 1994. Map values are given for the pixel at the fire location and the lowest pixel value immediately adjacent to the east, or north if different, recognizing that the fire location may not be exact. These large fires generally burned toward the northeast well beyond a 1-km cell and the registration of satellite data may be off a half pixel in any direction.

Some fire locations (such as Henry Peak) indicate average greenness (a DA value of 99-101 percent) prior to mid August. Note that these same locations show less greenness than their full potential (RG below 100 percent), indicating curing vegetation or reduced plant growth. Observation of the full sequence of maps indicates whether vegetation is past its maximum and curing or is exhibiting reduced growth.

It should be noted that at all times during the season, there were areas at high greenness values. Portions of the west side of Glacier National Park, for example, where the Howling Fire was successfully managed as a prescribed natural fire, maintained both high RG and DA values. Additional study of fire occurrence and vegetation condition is planned once a full fire data set is available.

Table 1--Percent Relative Greenness and Percent Cumulative Departure from Average Value at the fire location with lowest adjacent pixel value to the north or east (in parentheses) for the map composite period that includes fire ignition date.

Fire Name	Fire Date	Map Period	Percent RG Value	Percent CD Value
Robertson	07/01	07/07	55(51)	100(98)
Chezum	07/02	07/07	82(76)	100(102)
Buffalo Jump	07/05	07/07	71(64)	97(95)
Badger Pass	07/11	07/14	54(46)	99(98)
Crystal Lake	07/21	07/21	90(80)	96(95)
Henry Peak	07/26	07/28	86(69)	101(97)
Niarada	07/26	07/28	26(19)	89(88)
Livermore	07/31	08/04	93(65)	103(97)
Perma	08/01	08/04	56(44)	96(93)
E.Fk.Chamberlain	08/02	08/04	95(86)	104(98)
Freezeout	08/02	08/04	26(28)	99(95)
Tern	08/06	08/11	11(19)	82(85)
Border	08/06	08/11	58(46)	94(91)
Sponge	08/11	08/11	70(54)	93(96)
Hidden Ck	08/14	08/18	45(36)	90
Little Wolf	08/14	08/18	57(18)	95(87)
Starvation	08/14	08/18	26(28)	88(86)
Ann	08/16	08/18	28(16)	85
Zimmerman Hill	08/16	08/18	79(67)	99(95)
Deckard Flats	09/03	09/08	29(43)	89(90)
Baby Dean	09/08	09/08	24(16)	99(98)
Windy Point	09/09	09/15	38(27)	88(85)
Siam	09/25	09/15	75(73)	97(92)
Ward Mountain	09/26	09/15	35(33)	96(95)
Missouri River	09/26	09/15	84(68)	98(96)

Fire occurrence can be related to vegetation condition in a regional perspective comparison. Figure 7 illustrates the percent of the map area that was covered by vegetation at less than average greenness (DA less than 99 percent). Also shown is the percent of the area at less than 50 percent RG following a similar trend. The fire occurrence is portrayed by the cumulative number of fires. Prior to full greenup, the percent of the area at RG values less than 50 percent is declining while the percent of the area at DA values less than 99 percent is variable. Looking back to figure 2, note that the increased area departing from average greenness (DA) in late June corresponds with an increase in fire activity. Peak greenness occurred over the region in general during the first week of July. The decrease in area departing negatively from average greenness during the peak greenness period corresponds to a brief decline in fire activity. Following the peak in greenness, the rate at which the vegetation was curing, as shown by both the DA and RG values, matches well the rate at which fires were occurring. Given less frequent lightning, this relationship might not appear as strong. However, given adequate ignition sources, new fires occurred at about the same rate that vegetation cured.

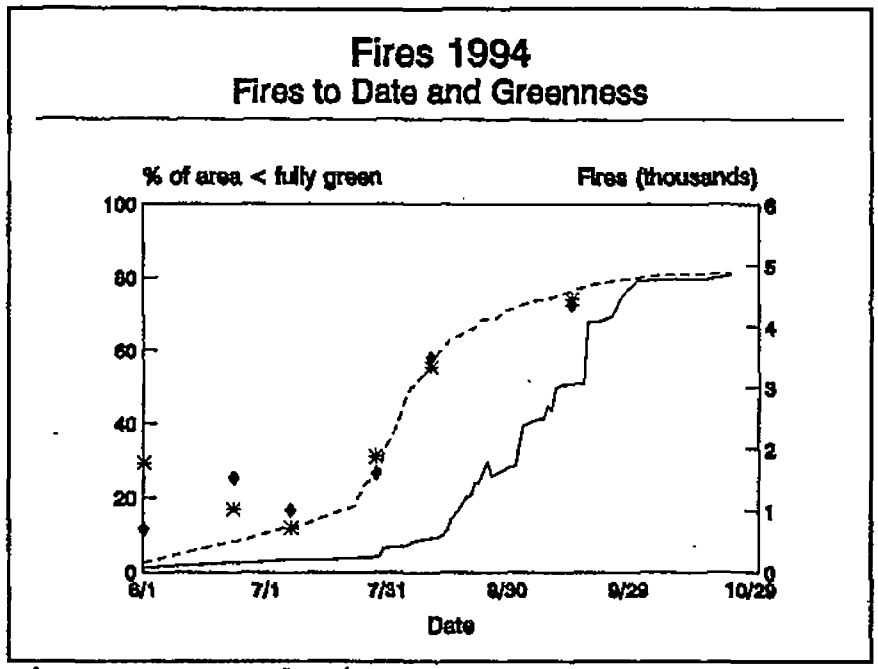

Figure 7--Cumulative number of reported fires (dashed line), percent of area with DA<99% (*), and percent of area with RG<50% (+).

Compare figure 7 to figure 4. The relationship between vegetation condition change and rate of increase in burned acres is not as close. Once 60 to 70 percent of the general area had declined to DA values less than 99 percent of average and RG values less than 50 percent, the rate of increase in acres burned substantially accelerated. Further examination of other years and other areas may help identify a critical greenness value at which rapid fire growth could be expected in the absence of wind.

SUMMARY OF THE USEFULNESS OF NDVI-DERIVED MAPS

Weekly use of NDVI-derived maps offers managers a spatial display of live vegetation condition at 1 km resolution. Timing and extent of greenup and curing are readily observable on the Relative Greenness maps. A sense of the amount of live vegetation that has been produced, compared to the maximum possible on a site, is observed by looking at the maximum relative greenness reached through the growing season. The amount of live, green vegetation compared to average for the date can be observed on the Cumulative Departure from Average maps. Distinct areas exhibiting drought stress in relation to adjacent areas and in relation to the average condition are displayed.

Remote sensing analysis strongly correlates rate of curing to fire occurrence in the 1994 fire season in the Northern Rockies. Large fires were more likely to occur in areas displaying less

than average greenness or in areas immediately adjacent to those appearing drought stressed.

Further study of the relationship between fire occurrence and size and NDVI-derived maps is planned to include other years and other parts of the United States.

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